Green and Golden Bell Frogs in New South Wales: current status and future prospects.

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ABSTRACT

Surveys carried out between 1990 and 1995 of almost all known historic locations within New South Wales (including the ACT) for the Green and Golden Bell Frog *Litoria aurea* revealed that the species had suffered a dramatic decline in distribution and abundance in this region, with over 80% of all historic populations having gone extinct, and many of the extant populations being reduced to low numbers. The present study involved surveys of the Green and Golden Bell Frog locations that were known in 1995, surveys of new locations or potential areas for new locations of this species, and review of management plans and other documented information concerning particular populations. Over the last 12 years extinctions have continued with the loss of almost 50% of those sub-populations and 23% of populations known in 1995. Obviously the species cannot sustain this rate of loss for much longer and continue to exist within New South Wales. Protection for remaining extant populations is very limited and most are under continuing threat. Management plans have been prepared in relation to a number of sub-populations/ populations, but these plans have not focused on populations under current threat, and associated management actions designed to benefit this frog have occurred in only a few cases. Hence, decline of this species within NSW is likely to continue.

Habitat change, mostly through destruction and disturbance, has been the major factor in population loss with the likelihood of extinction increasing with increases in the extent of habitat loss as measured by the number of habitat variables that have declined. Invasion by exotic predatory fish *Gambusia holbrooki*, previously linked with declines in this frog species, shows no apparent association with extinction of populations over the last 12 years and poses no apparent current threat to any population, apparently because any impact of this species has been ameliorated through the presence of submerged/ floating aquatic vegetation which may provide some protection against predation for eggs and tadpoles. The steps most likely to improve the conservation status of the Green and Golden Bell Frog within the state are habitat enhancement/ development and restoration of movement links between nearby populations.

Key words: Green and Golden Bell Frog, ***Litoria aurea***, conservation, populations, sub-populations, survey.

Introduction

Based on collective expert opinion the Green and Golden Bell Frog *Litoria aurea* was listed as 'endangered' in New South Wales (NSW) in 1991 (Lunney and Ayers 1993; Lunney *et al.* 1996). Surveys that we carried out between 1990 and 1995 of almost all known historic locations in NSW (including the ACT) for the Green and Golden Bell Frog further revealed that the species had suffered a dramatic decline in distribution and abundance in this region, with over 80% of all historic populations having gone extinct and many of the extant populations being reduced to low numbers (White and Pyke 1996). Of the 134 historic locations where the bell frog had been recorded prior to 1990 only 25 (including 6 that were previously omitted – see below) still contained these frogs after 1990, and designation of this species as 'endangered' in NSW certainly seemed justified (White and Pyke 1996). The total number of known 'locations' for this species in NSW in 1995 was 47 because another 22 locations were found between 1990 and 1995 (White and Pyke 1996).

White and Pyke (1996) considered that the principal factors responsible for this decline were habitat loss or change, especially in terms of drainage patterns and quality, and invasion by the introduced fish *Gambusia holbrooki*. Other suggested factors that may have been involved include chytrid fungal disease and pollution (Hamer *et al.* 2004; Department of Environment and Conservation NSW 2005).

An understanding of the habitat requirements of the bell frog has encouraged and facilitated the protection, enhancement and development of suitable habitat for this species. The observation that it often occurred in essentially artificial habitat indicates that, with appropriate procedures, it should be possible to enhance or develop suitable habitat for the species (Pyke and White 1996, 2001). Studies of patterns of habitat-use by the species suggest that suitable breeding habitat consists of ponds or slowly moving water bodies that are shallow (i.e., less than 1 metre deep), sunny (i.e., exposed to direct sunlight for at least six hours a day during the

spring/summer period) and fish-free, contain open water, and experience certain kinds of disturbance regime such as through fluctuating water level or inflow of salty water (Pyke and White 1996, 2001; Pyke *et al.* 2002). Such studies have also suggested that the species requires low vegetation in which to forage and can shelter either under solid objects with broad contact to the ground (e.g. timber, rock, buildings and other human artifacts) or within thick low vegetation (e.g. at base of the plant *Lomandra* sp.). That this species can breed in some water bodies that contain *Gambusia* suggests that submerged aquatic vegetation in which tadpoles can shelter and hide may be important in such situations (van de Mortel and Goldingay 1998; Pyke and White 2000).

Since 1995, a number of conservation-related initiatives have targeted the Green and Golden Bell Frog at many of its known populations in New South Wales. These initiatives have included research/ monitoring programs (Pyke and White 2001; Christy and Dickman 2002; Hamer *et al.* 2002; Goldingay and Newell 2005a; Pyke 2005), evaluation of impacts of proposed human development (Kevin Mills & Associates 1997; Fanning *et al.* 1999; Forest Fauna Surveys Pty Ltd *et al.* 2003), preparation of management plans (Australian Museum Business Services 1998; Bower and Goldingay 1998; van de Mortel *et al.* 1998; Grenadier and Mahony 1999; Parsons 1999; Daly and Senior 2000), establishment of captive-breeding programs (Hobcroft 1997b, a; Porter 1999; White and Pyke 2002), creation of new or enhanced habitat areas (Rowley 2001), and translocation of captive-bred animals into such habitat areas (Rowley 2001; White and Pyke 2008). In addition, a Recovery Plan for the Green and Golden Bell Frog in NSW has recently been adopted (Department of Environment and Conservation NSW 2005).

The success or otherwise of these conservation initiatives is unclear, as is whether or not the species has been continuing to decline in NSW after 1995. Habitat creation and enhancement have been relatively successful at sites where the species was already present, with rapid colonization and breeding within these habitat areas, but so far completely unsuccessful at sites that initially lacked the species and received translocated animals (White and Pyke 2008). There has, however, been no general review of the extent to which management plans have resulted in management actions, or of how successful such actions have been. There has been no comprehensive review of the status of populations known in 1995, though some individual populations have been studied since then (Department of Environment and Conservation NSW 2005).The overall conservation status of the species has been reviewed on the basis of information available in 2001, but not more recently (Department of Environment and Conservation NSW 2005). Our aim in this study was to review the various conservation initiatives that have been directed at the Green and Golden Bell Frog in NSW, its current conservation status in this region, and how this has changed since 1995.

Methods

The present study involved inspections and habitat appraisals of the Green and Golden Bell Frog locations that were known in 1995, surveys of new locations or potential areas for new locations of this species, and review of management plans and other available documented information concerning particular populations. We did not consider frog disease, such as chytrid fungus, which has been linked to declines in some frog populations and has been found in a number of bell frog populations (M. Stockwell, University of Newcastle, pers. comm.). We have used additional information, both documented and undocumented, in a few cases where this information assisted our analyses (see below).

Locations, populations and sub-populations

We consider sites where bell frogs were recorded at locations within 5 km of one another, and with continuous suitable habitat for frog movement (i.e., moist or wet area with available shelter) in between, to be part of the one sub-population. Sites that were this close to one another but where there was no continuous habitat suitable for frog movement in between are considered to contain separate sub-populations. We group sub-populations together as populations if they were 5-10 km apart and between them there was habitat suitable for frog movement. Frog locations that were either further apart or lacked connecting movement habitat between them are considered separate populations. Movements have been followed over distances of up to about 1 km in a single night (Pyke and White 2001) and recaptures of marked individuals indicate that frogs may move repeatedly between ponds that are up to about 1 km apart (Pyke and White, unpubl.). Movements of up to about 5 km may therefore be relatively common. Observations of frogs up to about 10 km from the nearest possible breeding locations suggest that they may sometimes disperse over distances up to about 10 km (Pyke and White, unpubl.).

On the basis of these considerations, the 43 sub-populations that were known in 1995 were contained within 31 populations (i.e., those visited at least once before 1996; Table 1). However, these numbers and the identities of sub-populations differ from what we presented in our earlier tally (White and Pyke 1996). Five sub-populations/ populations (i.e., Broughton Island, Brundee-East, Jervis Bay – Murrays Beach, Kooragang Island, Maitland – Gilleston Heights) that we currently list as being extant in 1995 were not included in our published list (White and Pyke 1996) of "locations" where the species had been detected between 1990 and 1995. Broughton Island was not surveyed during this period but the other four sub-populations were inadvertently omitted. The report of a population at Ocean Shores and its inclusion as a known population (White and Pyke 1996) are now considered in error (Lewis and Goldingay 1999), and this population is no longer included. The two sub-populations in Yuraygir National Park that were previously considered distinct (i.e., Station Creek & Blue Lagoon (White and Pyke 1996)) are now considered to be part of a single sub-population.

Table 1. Survey periods and numbers of surveys, year when the Green and Golden Bell Frog was last recorded, status, surrounding land-tenure and current visible threats for each sub-population.

Population	Sub-population	# surveys up to 1995	# surveys (1998-2002, 2003-2007)	Year last recorded	Status	Surrounding land-tenure	Current threats in 2007
Arncliffe		18	22, 40	2007	Extant	Council Conservation Reserve	Habitat loss
Bellambi Lagoon		0	0, 2	2007	Extant	Council Recreational Reserve	Habitat loss
Botany Swamp	Eastlakes Golf Course	58	10, 10	1993	Extinct	Sydney Water leasehold	Habitat Loss
Botany Swamp	Mascot (Engine Pond)	4	4, 1	1993	Extinct	Sydney Airport	Habitat Loss
Botany Swamp	La Perouse	6	5, 3	1993	Extinct	National Park	Habitat Loss
Bowen Is		1	2, 6	2000	Unknown	National Park	Habitat loss
Broughton Is		3	30, 30	2007	Extant	National Park	None
Brundee	Brundee East	2	2, 3	2004	Extant	Private	Habitat loss
Brundee	Brundee West	4	1, 3	1994	Probably Extinct	Private	Habitat loss
Clyde		0	2, 2	2006	Extant	Private	None
Coomondery		6	1, 3	2000	Unknown	Private and National Park	Gambusia invasion; habitat loss
Culburra		0	1, 2	2004	Extant	Council Recreational Reserve	Drought; Salt water inundation
Currumbene	Butterfly Rd Quarry	0	1, 2	2004	Extant	State Forest	Drought
Currumbene	Currumbene Creek	0	1, 0	1999	Unknown	State Forest	Drought
Davistown		0	5, 23	2007	Extant	Other Council land	Habitat loss
East Hills		3	3, 1	1995	Probably Extinct	Private	Habitat loss
Greenacre	Cox's Creek	10	7, 11	2004	Extant	Other Council land	Habitat loss
Greenacre	Enfield Marshalling Yards	4	10, 22	2006	Extant	State Govt - Industrial	Isolation from other sub-populations
Greenacre	Juno brickpit	4	28, 32	2007	Extant	Private	Isolation from other sub-populations
Greenwell Point		2	2, 1	2006	Extant	Private	Habitat loss
Hammondville		3	4, 1	1996	Extinct	Other Council land	Habitat loss
Hat Head		0	1, 5	2007	Extant	National Park	None
Hexham	Hexham Swamp & Sandgate	4	6, 10	2005	Extant	Private[1]	Habitat loss
Holsworthy		5	4, 0	1994	Probably Extinct	Military Land	Gambusia invasion
Homebush	Newington	10	17, 22	2007	Extant	State Govt - Reserve	None
Homebush	Sydney Olympic parklands	47	17, 22	2007	Extant	State Govt - Reserve	None
Jervis Bay	Murrays Beach	5	2, 3	2002	Probably Extant	National Park	Habitat loss
Jervis Bay	Ryans Swamp	5	2, 3	1996	Extinct	National Park	Habitat loss
Killalea Lagoon		3	3, 0	1992	Probably Extinct	Private	Habitat loss combined with fish
Kioloa		2	1, 4	2006	Extant	Nature Reserve	None
Kooragang Is		1	2, 15	2007	Extant	Private and Nature Reserve	Habitat loss
Kurnell	Kurnell N	27	6, 10	2001	Unknown	Private	Habitat loss

Table 1. (Cont.)

Population	Sub-population	# surveys up to 1995	# surveys (1998-2002, 2003-2007)	Year last recorded	Status	Surrounding land-tenure	Current threats in 2007
Kurnell	Kurnell S	14	20, 48	2007	Extant	Private	None
Kurnell[2]	Wanda	6	4, 10	1998	Extinct	Other Council land	Habitat loss
Kurnell	Woolooware	6	4, 10	1994	Extinct	Other Council land	Habitat loss
Liverpool		3	2, 0	1992	Probably Extinct	Private	Habitat loss
Maitland – Browns Quarry		0	1, 1	2000	Unknown	Private	Habitat loss
Maitland – Gilleston Heights		1	1, 1	2004	Extant	Private	Habitat loss
Medowie		0	0, 1	2007	Extant	Council Stormwater Corridor	Water Pollution
Meroo Lake		0	1, 3	2007	Extant	National Park	None
Merrylands[3]		0	4, 1	1998	Extinct	Private	Habitat loss
Milperra		2	3, 2	1992	Extinct	Other Council land	Habitat Loss
Molonglo		0	0, 1	2006	Extant	Private	None
Mount Druitt		5	4, 3	1994	Extinct	State Govt	Habitat loss
Nowra	Bens Walk	1	3, 3	1994	Extinct	Other Council Land	Habitat Loss
North Ryde[4]		4	3, 0	1992	Extinct	Private	Habitat loss
Nadgee		2	1, 0	1993	Unknown	National Park	None
North Avoca		0	23, 25	2007	Extant	Other Council land	Habitat loss
Port Kembla	BHP	0	1, 2	2007	Extant	Private	Unknown
Port Kembla	Boilers Point, Bricks & Mortar, Coomaditchy & South Pond	5	8, 24	2007	Extant	Private & Other Council land	Habitat loss; Gambusia; Pollution
Port Kembla	Koorungulla	3	4, 13	2006	Extant	Other Council land	Gambusia
Port Kembla	Primbee Golf Course	3	8, 1	1994	Extinct	Other Council land	Habitat loss
Port Macquarie-North Shore		0	1, 3	2001	Probably Extant	Other Council land	Habitat loss
Port Macquarie – Wangi Place		0	0, 3	2006	Extant	Other Council land	None
Ravensworth		1	1, 0	1994	Unknown	Private	Unknown
Riverstone		0	0, 2	2007	Extant	Private	Habitat loss
Rosebery	Dalmeny	0	0, 6	2007	Extant	Private	Habitat loss
Rosebery[5]	State Super	12	8, 0	1999	Extinct	Private	Habitat loss
Shoalhaven Heads		2	5, 0	1996	Extinct	Private	Habitat loss
Smiths Lake		13	13, 15	2004	Extant	National Park	Habitat loss
Sussex Inlet		0	0, 2	2005	Extant	Other Council land	None
Woonona		0	13, 30	2007	Extant	Private	Competition with other frog species
Yuragir	Station Creek	3	1, 5	2006	Extant	National Park	Habitat loss
	Diggers Camp	0	4, 0	2000	Probably Extant	National Park	None

1. Area where bell frogs are considered extant (i.e., Sandgate) is private land
2. All bell frog habitat at Wanda has been destroyed
3. All bell frog habitat at Merrylands has been destroyed
4. Jean Joss has visited the site many times since 1992 and observed that a number of frog species have colonised it. She has not detected any bell frogs during this period.
5. The two Rosebery sub-populations are only about 500 m apart but frog movement between them would have been difficult or impossible. All habitat for the State Super sub-population has now been destroyed.

New locations

Over the last decade, considerable effort has been invested in attempting to find previously unknown populations of the Green and Golden Bell Frog in NSW. The general community has been aware of the conservation status of this species, its appearance and to-some-extent its call, and we have received many reports from members of the community regarding possible detection of the species. Not surprisingly, however, almost all these reports have turned out to be the result of miss-identification of other frog species, and we followed through on just the few reports we considered credible. We have also received reliable reports of new locations for the species from fellow field biologists who may have encountered the species by chance. There have, in addition, been extensive targeted surveys by various people of areas where, based on mapped information concerning various habitat features, potential habitat for the species was considered to occur. Such surveys have been carried out for coastal areas north of Sydney (Lewis and Goldingay 1999; White 2001a), coastal areas south of Sydney (Daly 2000; Scanlon 2000; Daly 2003; Daly and Senior 2003) and the southern tableland (Osborne *et al.* 1996; Wassens and Mullins 2001). As a result of these efforts, a total of 17 new populations (comprising 18 sub-populations) were discovered (i.e., those not visited before 1996; Table 1). One additional sub-population was also discovered for each of three populations that were known in 1995 (i.e., Pt Kembla, Rosebery & Yuraygir; Table 1). The present study therefore considers a total of 64 sub-populations (i.e., 43+18+3). It does not include recent attempts to establish new populations by habitat construction and translocation (White and Pyke 2008).

Habitat assessments and population surveys

Prior to 1996 we carried out daytime and night-time inspections of all known Green and Golden Bell Frog sites, and since then we have similarly visited all newly-discovered sites, as well as all but one of those known in 1995. For each of these populations, we visited recorded locations for the species such as particular water-bodies, as well as the areas around each location. The timing of surveys to these sites has been generally opportunistic, depending on when one or both of the authors were in the general area (Table 1). It has not been possible for us to get access to the Ravensworth population.

Habitat assessments were carried out during daytime inspections around previously-recorded locations and around new locations. During these inspections we recorded general habitat features, surveyed for tadpoles and small fish, and recorded any detected frog species. Habitat features included area of open water, water depth, nature and areas of fringing vegetation, emergent vegetation, submerged or floating aquatic vegetation, foraging habitat (i.e., vegetation < 30 cm high) within 50 m, and suitable shelter for frogs (e.g., thick low vegetation, rocks, logs, fallen timber or artificial shelter) within 50 m, and surrounding land uses. Habitat areas were estimated visually and assigned to six categories (i.e., 0, 0-1, 1-10, 10-20, 20-50, 50-100 & 100+ sq m). All freshwater bodies within 200 m of the recorded location were sampled for tadpoles and small fish visually and by using a long-handled dip net. Any captured animals were identified on the basis of known species traits that have now been documented (Allen *et al.* 2002; Anstis 2002), and all were released unharmed after identification. The degree of connectivity of the site with other habitat areas was determined by traversing the site on foot to see if there were vegetated movement corridors between the site and these other areas. We also determined the tenure of the land surrounding each site (e.g., national park, nature reserve, private) and made visual assessments of the nature and extent of any current threats to each site. In cases where there had been a change in habitat we recorded whether the change was attributable to human or natural cause.

During night-time inspections we carried out auditory and visual surveys for frogs. At each water body, all calling frogs were identified and recorded, and then call imitation and call playback (using a small portable cassette recorder) were used to try to elicit calling by Green and Golden Bell Frogs. Calls were played for one minute and followed by a 2-minute quiet (listening) period. This was repeated five times. After completion of an auditory survey, we searched the area around the water-body and other nearby areas of potential Green and Golden Bell Frog habitat (e.g. foraging or shelter habitat) for non-calling frogs that were either exposed and visible, or hidden beneath potential shelter such as logs, rocks or other solid ground cover. We attempted to capture by hand any bell frogs that were encountered, and any captured individuals were weighed, measured, sexed and then released. At some sites (Arncliffe, Broughton Island (see Apendix 1, Fig. A1), Davistown, Greenacre (Fig. A2), Hat Head (Fig. A3), Long Reef, North Avoca (Fig. A4), Port Kembla, Sandgate (Fig. A5), South Kurnell and Woonona), the bell frogs have been micro-chipped (Christy 1996; Pyke 2005) as these sites have been revisited on a more regular basis than the other sites.

Population and sub-population status

We used our surveys and other available information to categorize sub-populations as extant, probably extant, probably extinct, extinct, or of unknown status. We consider that a sub-population is extant if surveys of it have been carried out during the last 5 years (i.e., 2003-2007) and if individuals have been detected during that period, and probably extant if the species was not detected during the last 5 years when five or fewer surveys have been carried out and the species was detected during the previous 5 years. A sub-population is considered extinct if no individuals have been detected during the last 10 years (1998-2007) despite attempts to locate the species on at least 5 occasions or all bell frog habitat has been lost. A sub-population is considered probably extinct if no individuals have been detected during the last 10 years but attempts to locate the species have been carried out on fewer than 5 occasions. A sub-population has unknown status if it cannot be categorized as above.

We categorize population status on the basis of the most optimistic assessment for its constituent sub-populations. A population is considered extinct, for example, only if

all its component sub-populations are considered extinct. The determination of population and sub-population status is mainly reliant upon our own field data, but, in some cases, additional information in the form of personal information or unpublished reports has been used.

Statistical analyses

The relationships between whether or not a sub-population went extinct (i.e., considered extinct or probably extinct in 2007) and other variables (i.e., geographic region, habitat change, presence/ absence of Gambusia) were analysed using forward stepwise log-linear analysis. Habitat change was separately considered in terms of habitat decline vs other habitat changes (i.e., no change or habitat improvement), number of habitat variables showing decline, and number of habitat declines excluding cases where there were no declines. To evaluate the effect of number of habitat variables showing decline, a binary probit analysis was carried out. One-tailed tests were used to evaluate the effects of habitat decline. In all cases the status of each sub-population was scored as 1 if it was considered to be still extant or probably still extant in 2007 and 0 if it was considered to have gone extinct or probably gone extinct between 1995 and 2007. This sub-population status was then taken as the dependent variable.

Results

Status of sub-populations and populations

Extinctions and probable extinctions have occurred for a number of sub-populations and populations that were known in 1995. Of the 43 sub-populations that were known in 1995, we consider 15 to be extinct (35% of the sub-populations) and 5 to be probably extinct (12%) (Table 1). Of the 31 populations known in 1995, we consider 7 to be extinct (23%) and 4 to be probably extinct (i.e., 13%) (Table 1). In addition, recent habitat changes (i.e. habitat destruction) for one sub-population/ population that was known in 1995 (i.e., Maitland-Gilleston Heights), suggests that it too is now probably extinct (Pyke & White, pers. obs.). All but one of the sub-populations discovered since 1995 are considered extant or probably extant (Table 1). The current status of the Browns Quarry/ Maitland sub-population is unknown, because it has been infrequently surveyed (Table 1). In addition, the Hexham - Sandgate sub-population appears recently lost due to the flooding of salt water into the breeding habitat (White, pers. obs.).

Extinctions have occurred throughout the range of the species, with no apparent geographic bias. Where the current sub-population status is known, extinctions or probable extinctions occurred between 1996 and 2007 for 1 out of 6 of the sub-populations that were known to exist north of Sydney in 1995, for 13 out of 20 of the Sydney sub-populations known then, and for 6 out of 12 of those sub-populations south of Sydney, with no significant relationship between likelihood of extinction and geographic region (χ^2=4.37; d.f.=2: P=0.11, Stepwise Log-linear Analysis). The fates of five of the sub-populations known in 1995 are unknown.

Factors associated with extinctions and probable extinctions

Over the period 1996-2007 most (70%; n=42) sub-populations that were known in 1995, and have been surveyed since then, experienced some kind of habitat change (Table 2). In most of these cases (26 out of 33 sub-populations) there was a decline in habitat suitability, with a decrease in area of suitable habitat in all but one of these cases, three cases also involving invasion by Gambusia, and one case involving just Gambusia invasion (Table 2). There were increases in area of suitable habitat in three cases and, in four cases, habitat changes were mixed, with both positive and negative changes occurring (Table 2). There was no apparent change in habitat in just 9 cases (21%).

In most cases (25 out of 33) these habitat changes were the direct result of human activity leading to some kind of habitat loss (Table 2). In seven cases, habitat changes were attributed to natural causes, as there was no apparent direct effect of human activity, and in one case habitat changes had apparently resulted from both human and natural causes (Table 2). In seven of the eight cases in which naturally-caused changes were considered to have occurred, the ponds dried up during the period 1996-2007, and in one case (i.e., Smith's Lake (Fig. A6)) pond size decreased through siltation.

Extinctions and probable extinctions have been associated with habitat decline in general, but cannot presently be associated with particular kinds of habitat decline. No sub-populations have gone extinct where available habitat has increased, and hence improved, or where there have been mixed changes in available habitat, and just one has gone extinct where there has been no apparent change in habitat (Fig. 1, Table 2). On the other hand, significantly more (i.e., 79%, n=24) of sub-populations have become extinct where available habitat has declined (Fig. 1, Table 2; χ^2=18.4, d.f.=1, P<0.0001, Stepwise log-linear analysis, comparing habitat declines with other habitat changes). None of the particular kinds of habitat change provide significant discrimination between those sub-populations that are considered to have gone extinct or probably gone extinct and those sub-populations that are considered to have remained extant or probably extant (P's>0.15; Linear Discriminant Analysis).

Extinctions and probable extinctions occurred increasingly often with increases in the extent of habitat decline. The proportion of sub-populations, that were known to be extant in 1995 and considered either to have remained so or probably remained so up till 2007, decreased significantly with increases in the number of habitat variables that have shown decline over the same time period (Fig. 2; χ^2=4.3, P=0.02, one-tailed binary probit analysis, # declines = 1, 2, 3 or 4=4-6).

Presence or invasion by Gambusia has not been significantly associated with extinction or probable extinction of sub-populations during the period 1996-2006, apparently because any impact of Gambusia was ameliorated through submerged/floating aquatic vegetation. Of the four sub-populations where there

Table 2. Habitat comparisons between 1995 and 2007. Values are the scores in each year (1995, 2007). Gambusia shows presence (1) or absence (0). Scores for habitat components represent area (sq m) of cover (0=0; 1=0-1; 2=1-10; 3=10-20; 4=20-50; 5=50-100; 6=100+).

Population	Sub-population	Gambusia (1995, 2007)	Open Water (1995, 2007)	Submerged/ floating Veg (1995, 2007)	Emergent Veg (1995, 2007)	Fringe Veg (1995, 2007)	Foraging (1995, 2007)	Frog shelter (1995 vs 2007)	Cause of habitat change
Arncliffe		0, 0	2, 3	2, 3	3, 3	4, 4	6, 6	Increase	Human
Bellambi Lagoon		-, 0	-, 2	-, 2	-, 3	-, 2	-, 6		
Botany Swamp	Eastlakes Golf Course[1]	1, 1	6, 6	5, 5	6, 6	6, 6	6, 6	Decrease	Human
Botany Swamp	Mascot(En gine Pond)	1, 1	6, 6	4, 2	6, 4	6, 6	6, 6	Decrease	Human
Botany Swamp	La Perouse	0, 0	2, 0	0, 0	1, 1	3, 3	5, 5	No change	Natural
Bowen Is		1, 1	1, 0	2, 2	3, 3	2, 2	6, 6	No change	Natural
Broughton Is		0, 0	2, 2	2, 2	2, 2	3, 3	6, 6	No change	
Brundee	Brundee East	1, 1	4, 4	4, 4	5, 5	3, 3	6, 6	Decrease	Human
Brundee	Brundee West	1, 1	3, 0	3, 1	2, 2	2, 2	4, 4	Decrease	Human
Clyde		-, 0	-, 5	-, 3	-, 3	-, 4	-, 6		
Coomondery		0, 0	6, 6	6, 6	6, 6	6, 6	6, 6	No change	
Culburra		-, 0	-, 3	-, 3	-, 6	-, 6	-, 6		
Currumbene	Butterfly Rd Quarry	-, 0	-, 4	-, 3	-, 3	-, 6	-, 4		
Currumbene	Currumbene Ck	-, 1	-, 2	0, 1	-, 1	-, 6	-, 3		
Davistown		-, 1	-, 3	-, 3	-, 3	-, 3	-, 6		
East Hills		1, 1	3, 0	3, 2	3, 3	3, 3	6, 6	Decrease	Human
Greenacre	Cox's Creek	1, 1	2, 1	2, 3	3, 3	2, 2	2, 2	Mixed	Human
Greenacre	Enfield Marshalling Yds	1, 1	4, 2	2, 4	3, 4	2, 2	3, 3	Mixed	Human
Greenacre	Juno brickpit	0, 0	5, 3	2, 3	2, 2	2, 2	4, 4	Mixed	Human
Greenwell Point		0, 0	2, 2	3, 3	3, 3	4, 4	6, 6	No change	
Hammondville		1, 1	5, 5	4, 3	4, 3	2, 2	4, 4	Decrease	Human
Hat Head		-, 0	-, 6	-, 3	3	3	-, 6		
Hexham[2]	Hexham Swamp & Sandgate	1, 1	6, 6	4, 3	6, 6	6, 6	6, 6	Decrease	Human
Holsworthy		1, 1	2, 1	1, 1	1, 1	2, 2	2, 2	No change	Human
Homebush	Newington	1, 1	2, 6	2, 6	6, 6	6, 6	6, 6	Increase	Human
Homebush	Sydney Olympic parklands	0, 0	4, 6	4, 6	3, 6	6, 6	6, 6	Increase	Human
Jervis Bay	Murrays Beach	0, 0	6, 6	5, 5	3, 3	4, 4	6, 6	No change	
Jervis Bay	Ryans Swamp[3]	1, 1	6, 6	3, 3	4, 4	6, 6	6, 6	Decrease	Natural
Kilalea Lagoon		0, 0	4, 1	6, 5	6, 6	6, 6	6, 6	No change	Natural
Kioloa		0, 0	3, 3	3, 3	3, 3	5, 5	6, 6	No change	
Kooragang Is		1, 1	6, 6	6, 6	6, 6	6, 6	6, 6	No change	
Kurnell	Kurnell N	0, 1	3, 2	4, 3	3, 3	4, 4	5, 4	Decrease	Human
Kurnell	Kurnell S[4]	0, 1	6, 6	6, 6	6, 6	6, 6	6, 6	Mixed	Human
Kurnell	Wanda	0, 0	2, 0	3, 2	4, 2	3, 2	2, 2	Decrease	Human

Table 2. (Cont.)

Population	Sub-population	Gambusia (1995, 2007)	Open Water (1995, 2007)	Submerged/ floating Veg (1995, 2007)	Emergent Veg (1995, 2007)	Fringe Veg (1995, 2007)	Foraging (1995, 2007)	Frog shelter (1995 vs 2007)	Cause of habitat change
Kurnell	Wooleware	0, 0	2, 0	3, 2	3, 3	3, 2	4, 3	No change	Natural
Liverpool		0, 0	5, 0	4, 3	3, 3	3, 3	6, 4	Decrease	Human
Maitland – Browns Quarry		-, 0	-, 4	-, 3	-, 3	4	-, 4		
Maitland – Gilleston Heights		0, 0	4, 2	2, 2	3, 3	2, 2	4, 4	Decrease	Human
Medowie		-, 0	-, 1	-, 5	-, 5	-, 6	-, 6		
Meroo Lake		-, 1	-, 4	-, 4	-, 6	-, 6	-, 6		
Merrylands		-, 0	-, 3	-, 2	-, 2	-, 2	-, 4		
Milperra		0, 0	3, 0	1, 0	3, 0	3, 0	6, 6	Decrease	Human
Molonglo		-, 0	-, 3	-, 2	-, 3	-, 3	-, 6		
Mt Druit		1, 1	2, 2	2, 2	3, 3	4, 4	6, 6	No change	
Nowra	Bens Walk	0, 0	3, 0	1, 0	2, 0	2, 0	6, 6	Decrease	Human
N Ryde		0, 1	4, 4	3, 3	3, 3	2, 2	2, 2	Decrease	Human
Nadgee		1, 1	4, 4	4, 4	3, 3	4, 4	6, 6	No change	
North Avoca		-, 0	-, 4	-, 3	-, 3	-, 2	-, 6	No change	
Port Kembla	BHP	-, 1	-, 6	-, 6	-, 6	-, 6	-, 6		
Port Kembla[5]	Boilermakers Pt., Bricks & Blocks, Coomaditchy, South Pond	1, 1	6, 6	6, 6	6,6	6, 6	6, 6	Decrease	Human & natural
Port Kembla	Koorungulla	0, 0	4, 4	4, 4	6, 6	5, 5	6, 6	No change	
Port Kembla	Primbee Golf course	0, 1	4, 2	3, 2	2, 2	2, 2	6, 6	Decreased	Human
Port Macquarie - North Shore		-, 0	-, 2	-, 2	-, 2	2	-, 4		
Port Macquarie - Wangi Place		-, 0	-, 2	-, 2	-, 2	4	-, 6		
Ravensworth		0, -	4, -	3, -	3, -	5, -	6, -	-	
Riverstone		-, 0	-, 2	-, 2	-, 1	-, 2	-, 3		
Rosebery	Dalmeny	-, 0	-, 2	-, 1	-, 1	-, 2	-, 2		
Rosebery	Sate Super	0, 0	2, 0	2, 0	1, 0	2, 0	2,0	Decrease	Human
Shoalhaven Heads		0, 1	4, 3	2, 2	3, 3	2, 2	6, 6	No change	Human
Smith's Lake		0, 0	4, 2	6, 4	6, 6	6, 6	6, 6	No change	Natural
Sussex Inlet		-, 0	-, 2	-, 2	-, 3	-, 2	-, 6		
Woonona		-, 0	-, 6	-, 6	-, 6	-, 6	-, 6		
Yuragir	Station Ck	0, 0	6, 6	6, 6	6, 6	6, 6	6, 6	No change	Natural
	Diggers Camp	-, 0	-, 6	-, 0	-, 0	-, 0	-, 6		

1. Although total available habitat areas remain above 100 m^2, the breeding ponds (i.e., 4 habitat variables) have been destroyed along with associated foraging habitat
2. This assessment does not include the area known as 'Sandgate', which was not a recorded bell frog site in 1995.
3. There have been noticeable decreases in areas of open water, floating/ submerged vegetation and emergent vegetation, though areas of available habitat remain above 100 m^2 for all of these
4. Despite the loss of some foraging area and a breeding pond, there have been overall increases in breeding and foraging habitat through the development of additional breeding ponds and vegetation suitable for foraging.
5. This assessment does not include the areas known as 'Bricks & Blocks' and 'South Pond', which were not recorded bell frog sites in 1995. Though there have been no overall changes in levels of habitat availability, there have been decreases in the area known as 'Boilermaker's Point' in the extent of open water, suitable shelter and submerged vegetation, even though an additional pond was created there in 1997.

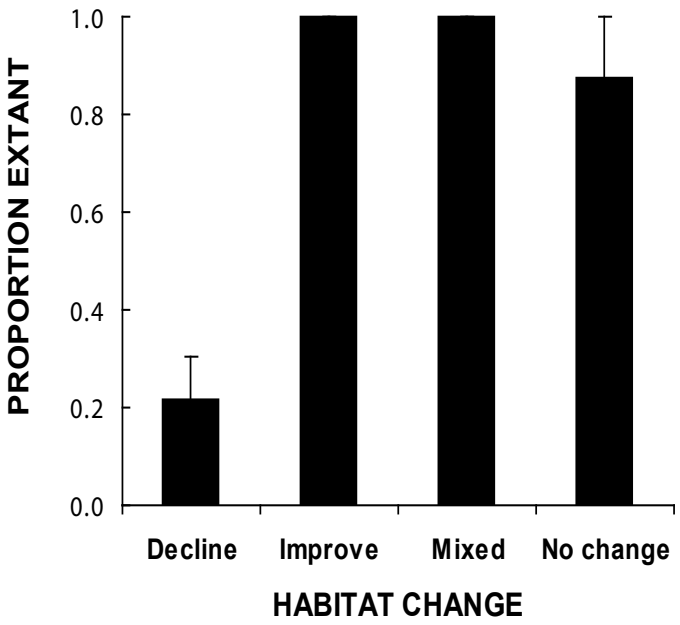

Figure 1. Proportion of *Litoria aurea* sub-populations known in 1995 that have remained extant during the period 1996-2006 (± 1 s.e. as appropriate) vs nature of habitat change

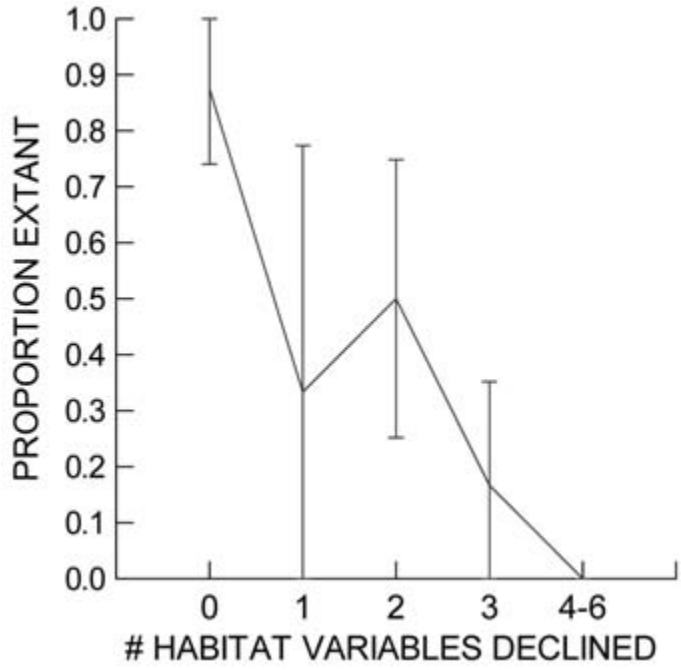

Figure 2. Proportion of *Litoria aurea* sub-populations known in 1995 that have remained extant during the period 1996-2006 (See Table 1) vs number of habitat variables that have declined (see Table 3)

has been invasion by Gambusia since 1995 and where current status of the Green and Golden Bell Frog is known, two are considered to have gone extinct and in both cases there has also been a decrease in habitat area (i.e., Shoalhaven Heads, Primbee Golf Course; Table 2). Of the 15 sub-populations where Gambusia was present in 1995 and where the current status of *L. aurea* is known (comprising 40% of known sub-populations in 1995), nine (i.e., 60%) have either gone extinct or probably gone extinct (Tables 1 & 3), with other kinds of habitat decline having occurred at all sites (Table 2). Of the 23 sub-populations where Gambusia was absent in 1995 and where the current status of *L. aurea* is known, a lower proportion (i.e., 39%) have gone extinct or probably gone extinct but extinction was not significantly related to Gambusia (χ^2=0.54, d.f.=1, P=0.46; forward stepwise loglinear analysis). As expected, for those sub-populations considered extant in 2007, there was significantly more submerged/ floating vegetation in cases where Gambusia was present than in cases where it was absent (Test statistic = 32, P=0.002; one-tailed Mann-Whitney U test).

Current and future prospects

Most (i.e., 65%, n=37; Table 1) extant or probably extant sub-populations were under ongoing or pending threat in 2007, mostly (i.e., 17 out of 24 cases) from possible loss of habitat within the site (Table 1). A few sub-populations were threatened by other factors, including two sub-populations that were threatened through possible invasion by *Gambusia*, and the situation regarding threat was unknown for one sub-population (Table 1).

Protection of the sub-populations considered extant or probably extant in 2007 is low. Only 32% (n=37) of these sub-populations occur within a conservation reserve (i.e., National Park, Nature Reserve, State Government Reserve, Council Conservation Reserve) and hence would be expected to have a high level of protection (Table 1). About 35% of the sub-populations (i.e., 13 out of 37) occur within other kinds of government land (i.e., Council Recreation Reserve, Other Council land, State Forest, Military or State Government industrial land) and hence would be expected to receive lower levels of protection (Table 1). About 46% of sub-populations (i.e., 17 out of 37) were either partly or completely surrounded by private land and so would receive little or no protection (Table 1). The only protection provided is from direct habitat loss.

Furthermore, some of the sub-populations that were considered extant or probably extant in 2007 and occurred within a conservation reserve are still under some kind of on-going or pending threat. Of the seven such sub-populations, five are threatened with loss of habitat (Table 1).

Conservation-related activities and their effectiveness

Conservation-related activities have been carried out for some of the sub-populations/ populations known in 1995 or discovered since. Management plans, or their equivalent, have been developed for 18 sub-populations (representing 17 populations) (Table 3). Management actions have been carried out for 8 sub-populations (representing 8 populations) (Table 3). Captive populations exist for 4 populations; the Rosebery population was maintained in captivity until 2005 (Table 3). Some kind of conservation-related activity has been carried out for 21 sub-populations (representing 20 populations) (Table 3). The remaining 40 sub-populations have not been

Table 3. Conservation-related activities for sub-populations/ populations of *L. aurea*.

Population	Sub-population	Management Plan (or equivalent)	Management Actions	Locations of any captive populations
Arncliffe		White (1997, 1998)	New ponds	Taronga Zoo (White 1998)
Bowen Is		Biosphere Environmental Consultants (1999); White (1999c)		
Broughton Is				Australian Reptile Park
Culburra		Grenadier and Mahony (1999)		
Currumbene	Butterfly Road Quarry	Bower and Goldingay (1998)		
Davistown		White *et al.* (2006)	New ponds	Australian Reptile Park
Greenacre	Juno brickpit	White (1999a)	New ponds and associated terrestrial habitat	
Hat Head		Parsons (1999)		
Hexham	Hexham Swamp		New ponds and associated terrestrial habitat	
Homebush	Newington & Sydney Olympic parklands	Greer (1993); Pyke (1995); Australian Museum Business Services (1998)	New ponds and associated terrestrial habitat	
Jervis Bay	Murrays Beach & Ryans Swamp	Biosphere Environmental Consultants (1999); White (1999c)		
Kurnell	Kurnell S	White (1999b)		
North Avoca		White *et al.* (2006)		Australian Reptile Park (Porter 1999)
Port Kembla	BHP	Goldingay and Lewis (1999)		
Port Kembla	Boilers Pt, Bricks & Mortar & Coomaditchy	van de Mortel *et al.*; (1998); Goldingay and Lewis (1999); Goldingay and Newell (2005b); White (2004)	New ponds and associated terrestrial habitat	
Port Macquarie – North Shore		White (2006)		
Port Macquarie – Wangi Place		White (2006)		
Rosebery	Dalmeny		New pond	Taronga Zoo (1993-2005)
Sussex Inlet		Daly and Senior (2000)		
Woonona		White (2001b); Kevin Mills & Associates and White (2002)	New ponds and foraging areas	
Yuragir	Station Creek	Gray (1999); Goldingay and Newell (2005a)		

subject to any conservation-related activity (cf. Tables 1 & 2). Monitoring of some sub-populations has been or is occurring, with varying degrees of frequency and regularity, but this activity does not, on its own, contribute to the conservation of the species.

Management plans (or their equivalent) have not focused to a greater extent on sub-populations that we consider to be currently threatened compared with ones that do not appear so. About half of the threatened sub-populations remain without a management plan, and management actions have been carried out in association with a small proportion of threatened sub-populations. Whether or not a management plan has been developed for a particular sub-population is not significantly related to whether it is currently visibly threatened (Tables 1 & 2; P=1.0, Fisher Exact Test). Management plans have been prepared for 48% (i.e., 14 of 29) of the currently threatened sub-populations and only 21% (n=29) of threatened sub-populations have so far received management actions aimed to benefit them (Tables 1 & 2). Habitat loss within or near to bell frog habitat has been the most common threat to populations of this species (Table 1) and have stimulated the preparation of management plans and associated documents that address these threats and propose ways whereby any negative impacts may be mitigated or avoided (Table 3). However, management plans/ recommendations have been developed for a number of sub-populations that are not currently visibly threatened, including some in conservation reserves (Tables 1 & 2).

The most common management action that has been designed to benefit the Green and Golden Bell Frog has been the enhancement or creation of breeding habitat, but most management plans have not been associated with any such management action. Management actions have been associated with only eight management plans out of a total of 25. In all cases new breeding ponds have been developed (Table 3) and these have been colonized and well-used by the species (White and Pyke 2008). Often additional foraging and shelter habitat has been created in association with the establishment of new breeding ponds (Table 3). All of the populations, for which management plans have been prepared, remained extant in 2007 (Tables 1 & 2).

Discussion

Decline in the distribution of the Green and Golden Bell within NSW has continued over the last 12 years at an alarming rate. The disappearance of the species by 1995 from over 80% of previously known locations has been followed by a further loss (i.e., extinctions and probable extinctions), over the subsequent 12-year period, of about 50% (n=38 where recent status is known) of remaining locations (i.e., sub-populations) that were known in 1995. Though 22 new sub-populations/populations have been discovered since 1995, one of these has already disappeared and there were presumably many populations that disappeared prior to 1995 without ever having been known. In addition, there are five sub-populations whose status is unknown and some of these may have gone extinct. Obviously the species cannot sustain this rate of loss for much longer and continue to exist within NSW. Within this region there are presently just 31 known populations, represented by 37 sub-populations, of the species that are considered extant or probably extant (Table 1).

It is not surprising that habitat decline emerged as the most significant factor in causing population loss in this species, as habitat decline has generally been found to be the most important factor responsible for species decline (Hazell 2003; Ewers and Didham 2006). Given the importance attributed to Gambusia in causing previous population losses in this species (Pyke and White 2001), the lack of any apparent association between population losses over the last 12 years and either presence or invasion by Gambusia was not expected. Apparently, however, any impact of Gambusia was ameliorated by the presence of submerged/ floating vegetation that may provide protection for tadpoles from Gambusia predation where it occurs.

Protection for remaining populations of Green and Golden Bell Frog exists but is limited. Most lie outside of conservation reserves and many are surrounded by private land. Most are under threat, with human development being the major cause. Only five populations that occur within a conservation reserve are considered unthreatened across all sub-populations (Table 1). Though 18 sub-populations, representing 17 populations, have been the subject of management plans or their equivalent, management actions aimed to benefit this species have been carried out in relation to only eight sub-populations, representing eight populations (Table 3). Unless this situation changes, decline in this species is likely to continue.

The steps most likely to improve the conservation status of the Green and Golden Bell Frog within NSW and the ACT are habitat enhancement/ development and restoration of movement links between nearby populations. Habitat enhancement and development have already had considerable success at sites where the species already occurred (Tables 1 & 2) (White and Pyke 2008). Movement of individuals between separate populations is believed to promote the survival of the combined population of that species and its component sub-populations (Belbin 1993).

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References

Allen, G.R., Midgley, S.H. and Allen, M. 2002. *Field Guide to the Freshwater Fishes of Australia*. Western Australian Museum, Perth, WA.

Anstis, M. 2002. *Tadpoles of South-eastern Australia: A guide with keys.* Reed New Holland, Sydney.

Australian Museum Business Services 1998. Management Plan for the Green and Golden Bell Frog (*Litoria aurea*) at Homebush Bay.

Belbin, L. 1993. Environmental representativeness: regional partitioning and reserve selection. *Biological Conservation* **1993**: 223-230.

Biosphere Environmental Consultants 1999. Resource Document and Plan of Management. Giant Burrowing Frog and Green and Golden Bell Frog. Booderee National Park.

Bower, H. and Goldingay, R. 1998. Management Plan for the Green and Golden Bell frog at the Butterfly Road Quarry, Currambene State Forest, New South Wales.

Christy, M. 1996. The efficacy of using Passive Integrated Transponder (PIT) tags without anaesthetic in free living frogs. *The Australian Zoologist* **30**: 139-142.

Christy, M.T. and Dickman, C.R. 2002. Effects of salinity on tadpoles of the green and golden bell frog (*Litoria aurea*). *Amphibia-Reptilia* **23**: 1-11.

Daly, G. 2000. Island populations: Reptiles and amphibians of the Jervis Bay Region on the south coast of New South Wales. *Herpetofauna* **30**: 11-17.

Daly, G. 2003. Surveys of amphibians at Meroo Lake and Termeil Lake, Meroo National Park 2002-2003. Report prepared by Gaia Research Pty Ltd for the NSW National Parks and Wildlife Service.

Daly, G. and Senior, C. 2000. Management plan for the population of Green and Golden Bell Frog at the Sussex Inlet wastewater treatment plant.

Daly, G. and Senior, C. 2003. Surveys for and habitat assessment of the Green and Golden Bell Frog *Litoria aurea* on the far south coast of New South Wales. *Herpetofauna* **33**: 86-102.

Department of Environment and Conservation NSW 2005. Green and Golden Bell Frog *Litora aurea* (Lesson 1829) Recovery Plan. Department Environment and Conservation (NSW).

Ewers, R.M. and Didham, R.K. 2006. Confounding factors in the detection of species responses to habitat fragmentation. *Biological Reviews* **81**: 117-142.

Fanning, F.D., Pepper, J.W., Budde, E., Chambers, M., Chamberlain, S. and de Lacey, C. 1999. Proposed Earthworks and Subsequent Development. Lot 113 DP777967, Captain Cook Drive, North Cronulla. Species Impact Statement.

Forest Fauna Surveys Pty Ltd, Fly By Night Bat Surveys Pty Ltd and TUNRA Ltd 2003. Mt Owen Operations. Species Impact Statement. Prepared for Hunter Valley Coal Corporation.

Goldingay, R. and Lewis, B. 1999. Development of a Conservation Strategy for the Green and Golden Bell Frog in the Illawarra Region of NSW. *Australian Zoologist* **31**: 376-387.

Goldingay, R.L. and Newell, D.A. 2005a. Aspects of the population ecology of the green and golden bell frog *Litoria aurea* at the northern end of its range. *Australian Zoologist* **33**: 49-59.

Goldingay, R.L. and Newell, D.A. 2005b. Population estimation of the green and golden bell frog *Litoria aurea* at Port Kembla. *Australian Zoologist* **33**: 210-216.

Gray, P. 1999. Recovery Action Strategy for the Green and Golden Bell Frog (*Litoria aurea*) in Yuraygir National Park, 1998/99.

Greer, A. 1993. Draft Faunal Impact Statement for proposed development works at the Homebush Bay Brick Pit.

Grenadier, L. and Mahony, M. 1999. Plan of Management for the Green and Golden Bell Frog (*Litoria aurea* at Culburra. "Draft".

Hamer, A.J., Lane, S.J. and Mahony, M.J. 2002. The role of introduced mosquitofish (*Gambusia holbrooki*) in excluding the native green and golden bell frog (*Litoria aurea*) from original habitats in south-eastern Australia. *Oecologia* **132**: 445-452.

Hamer, A.J., Makings, J.A., Lane, S.J. and Mahony, M.J. 2004. Amphibian decline and fertilizers used on agricultural land in south-eastern Australia. *Agriculture Ecosystems & Environment* **102**: 299-305.

Hazell, D. 2003. Frog ecology in modified Australian landscapes: a review. *Wildlife Research* **30**: 193-205.

Hobcroft, D. 1997a. Conservation program for the Green and Golden Bell Frog *Litoria aurea* at Taronga Zoo: A cooperative recovery plan.

Hobcroft, D. 1997b. Green and Golden Bell Frog *Litoria aurea* (Lesson 1829) Husbandry Manual.

Kevin Mills & Associates 1997. The Green and Golden Bell Frog. MM Kembla Wire & Rod. Prt Kembla. City of Wollongong.

Kevin Mills & Associates and White, A.W. 2002. Vegetation management plan incorporating the habitat management plan for the Green and Golden Bell Frog. Edgewood. City of Wollongong.

Lewis, B. and Goldingay, R. 1999. A preliminary assessment of the status of the Green and Golden Bell Frog in north-eastern NSW in *Declines and Disappearances of Australian Frogs*, edited by A. Campbell. Natural Heritage Trust and Environment Australia, Canberra, Australia.

Lunney, D. and Ayers, D. 1993. The official status of frogs and reptiles in New South Wales. Pp. 404-408 in *Herpetology in Australia. A Diverse Discipline*, edited by D. Lunney and D. Ayers. Royal Zoological Society of NSW, Sydney.

Lunney, D., Curtin, A., Ayers, D., Cogger, H.G. and Dickman, C.R. 1996. An ecological approach to identifying the endangered fauna of New South Wales. *Pacific Conservation Biology* **2**: 212-231.

Osborne, W.S., Littlejohn, M.J. and Thomson, S.A. 1996. Former distribution and apparent disappearance of the Litoria aurea complex from the Southern Tablelands of New South Wales and the Australian Capital Territory. *The Australian Zoologist* **30**: 190-198.

Parsons, M. 1999. Green and Golden Bell Frog. Management Strategy. Hat Head National Park.

Porter, R. 1999. The conservation of the Green and Golden Bell Frog (*Litoria aurea*) on the Central Coast of New South Wales. *Herpetofauna* **29**: 61-64.

Pyke, G.H. 1995. Fauna Impact Statement for proposed development works at The Homebush Bay Development Area, excluding the Brickpit. Prepared for Olympic Co-ordination Agency.

Pyke, G.H. 2005. The use of PIT tags in capture-recapture studies of frogs: A field evaluation. *Herpetological Review* **36**: 281-285.

Pyke, G.H. and White, A.W. 1996. Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* (Anura: Hylidae). *Australian Zoologist* **30**: 224-232.

Pyke, G.H. and White, A.W. 2000. Factors influencing predation on eggs and tadpoles of the endangered Green and Golden Bell Frog (*Litoria aurea*) by the introduced Plague Minnow (*Gambusia holbrooki*). *Australian Zoologist* **31**: 496-505.

Pyke, G.H. and White, A.W. 2001. A Review of the Biology of the Green and Golden Bell Frog (*Litoria aurea*). *Australian Zoologist* **31**: 563-598.

Pyke, G.H., White, A.W., Bishop, P.J. and Waldman, B. 2002. Habitat-use by the Green and Golden Bell Frog *Litoria aurea* in Australia and New Zealand. *Australian Zoologist* **32**: 12-31.

Rowley, J. 2001. Green & Golden Bell Frogs at Long Reef Golf Course. *Frogcall* **No. 53**: 7.

Scanlon, J.D. 2000. Notes on herpetofauna of Bendalong (South Coast of NSW), with reproductive data on elapid snakes and a range extension for *Hemiapsis signata*. *Herpetofauna* **30**: 36-41.

van de Mortel, T. and Goldingay, R. 1998. Population assessment of the endangered Green and Golden Bell Frog *Litoria aurea* at Port Kembla, New South Wales. *Australian Zoologist* **30**: 398-404.

van de Mortel, T.F., Goldingay, R.L., Daly, G., Buttemer, W.A. and Formosa, P. 1998. Management Plan for The Green and Golden Bell Frog at Coomaditchy Lagoon.

Wassens, S. and Mullins, B.J.D. 2001. Rediscovery of a Green and Golden Bell Frog Population in the Southern Tablelands. *Herpetofauna* **31**: 58-63.

White, A.W. 1997. Conservation Strategy. Strategy for compensatory habitat, monitoring and long-term maintenance of the Marsh Street wetlands, Arncliffe.

White, A.W. 1998. Plan of Management. Green and Golden Bell Frogs. Eve Street and Marsh Street Wetlands, Arncliffe. M5 Motorway Project.

White, A.W. 1999a. Eight Point Test. Enfield Brick Works. Enfield, NSW.

White, A.W. 1999b. Management Plan. Green and Golden Bell Frogs and Wallum Froglets. Cronulla Sewage Treatment Plant and Upgrade to Tertiary Treatment and Pipeline Duplication.

White, A.W. 1999c. Monitoring Plan. Green and Golden Bell Frog *Litoria aurea*. Booderee National Park.

White, A.W. 2001a. Green and Golden Bell Frog Gap Surveys. Mid-north Coast, New`South Wales. Prepared for the Department of the Environment and ConservationHurstville.

White, A.W. 2001b. Strategic Plan for the Development of Habitat for Green and Golden Bell Frogs. Woonona Brickpit Site.

White, A.W. 2004. Plan of Management. Green and Golden Bell frogs. Incitec Pivot, Port Kembla. Prepared for Incitec Pivot Pty Ltd.

White, A.W. 2006. Conservation Plan. Green and Golden Bell frogs, Port Macquarie District. Prepared for Hastings Shire Council.

White, A.W. and Pyke, G.H. 1996. Distribution and conservation status of the Green and Golden Bell Frog *Litoria aurea* in New South Wales. *Australian Zoologist* **30**: 177-189.

White, A.W. and Pyke, G.H. 2002. Captive frog egg numbers - A misleading indicator of breeding potential. *Herpetofauna* **32**: 102-109.

White, A.W. and Pyke, G.H. 2008. Frogs on the hop: translocations of Green and Golden Bell Frogs *Litoria aurea* in Greater Sydney. *Australian Zoologist* **34:** 249-260.

White, A.W., Pyke, G.H. and Bannerman, M. 2006. Plan of Management for the Green and Golden Bell Frog at North Avoca and Davistown. Prepared for Gosford City Council.

APPENDIX 1

Figure A1. Flat Rock, Broughton Island, Myall Lakes National Park; September 2004.

Photo, A. White.

APPENDIX I

Figure A2. Coxs Creek at Greenacre; March 1996.

Photo, A. White.

Figure A3. Ephemeral swales near Ryans Cut, Crescent Head (Hat Head population); October 2005.

Photo, A. White.

Figure A4. Bareena Wetland, Avoca Lagoon; December 2004.

Photo, A. White.

Figure A5. Sandgate main pond; December 2003.

Photo, A. White.

APPENDIX I

Figure A6. Dune pond, Smiths Lake, Myall Lakes National Park; November 2001.

Photo, A. White.